PRESENTATION OF THE

INSTITUTE OF PHYSICS OF MATERIALS

AS CR

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OUTLINE

1. Presentation of the Institute – scientific groups
2. Finished projects
3. Running projects
4. Future projects
Main research topic: mechanical properties x microstructure

Scientific persons: more physicist than engineers => focus on understanding of physical processes

110 employees; one half scientific, one half supporting staff

~ 200 publications / year

Some industrial contracts
Laboratories

Dept. of Mechanical Properties

- High cycle fatigue
- Low cycle fatigue
- Creep of metallic materials
- Advanced high temperature materials (creep II)
- Brittle fracture

Dept. of Structure

- Diffusion and thermodynamics
- Structure of phases
- Electrical and magnetic properties
EQUIPMENT

Mechanical properties

- 5 servohydraulic machines (fatigue, creep-fatigue)
- 5 resonant systems (high cycle fatigue, creep-fatigue)
- 3 screw driven machines
- Microforce Tytron (fibers, thin films)
- 31 creep machines (tensile, compressive, creep-fatigue, constant load or stress)
- 2 helicoid creep machines
- Torsional creep machine
- 3 impact testers
- Hardness, microhardness

Microstructure characterization

- TEM/STEM Philips CM12 + EDX
- SEM Jeol 6460 + EDX, WDX, EBSD
- SEM FIB Tescan Lyra 3 XMU
- EM accessories : Ion milling etc.
- X-ray diffractometers
- Mössbauer spectrometers
- Mass spectrometer
- Coercimeter, magnetometer
- Gamma spectrometer
- $\alpha$, $\beta$, $\gamma$ counters
Analytical transmission microscope with possibility of working in scanning mode (STEM), equipped with EDS

2 creep machines with lever arm mechanism up to 1200 (1600°C), protective atmosphere

Axial-torsion hydraulic testing system (fatigue) up to 1200°C

Electromechanical testing machine with vacuum furnace up to 1200°C
MATERIALS UNDER INVESTIGATION

- Steels: Eurofer, ODS ferrite steels, austenitic stainless 316, ferritic stainless, duplex stainless, P91 and other 9-12%Cr steels, dual ferritic-martensitic, bainitic
- Superalloys, inconels
- Intermetallics: Ni3Al, TiAl, Fe3Al, FeAl
- UFG materials (ECAP Cu, Mg, Al)
- Nanopowders
- Shape memory NiTi alloys
- Ceramics, nanoceramics
- Pb free solderings
- Light alloys – Al, Mg and its composites
- Model materials (single crystals Cu, Cu-Zn, Ge)
Exception: some ceramics and composites, processing by ECAP, thermal treatment etc.
HIGH CYCLE FATIGUE GROUP

- at present 7 scientific co-workers, 4 technicians, 5 PhD. students, 6 MSc. students

Study of nature and quantitative description of the fatigue process in all fatigue stages. Aim is contribute to the understanding of the cyclic plasticity at low amplitudes, crack initiation process, threshold values for fatigue crack propagation and to the fracture-mechanical description of the fatigue crack behaviour on the basis of experimental and theoretical study of relation between the microstructure, its development during cyclic loading and macroscopic fatigue and fatigue/creep properties.

Systematic investigation of fatigue behaviour and basic mechanisms is performed both on advanced engineering materials used in industry and in limited extent on model materials.

Topics:
- fatigue and fatigue/creep behaviour of single crystalline and polycrystalline superalloys,
- fatigue properties of ultrafine-grained materials,
- effect of mean stress on cyclic stress-strain response and fatigue life,
- effect of notches and cracks on fatigue life and fatigue/creep life,
- determination of crack-tip stress biaxiality parameters using finite element method,
- application of two-parameter fracture mechanics to crack and notch analysis,
- fracture mechanics of composite materials.
Resonant system Amsler, 20 kN, temperatures up to 600°C
HIGH CYCLE FATIGUE LABORATORY

- Servohydraulic system Zwick/Roell Amsler MC25, push-pull

- Resonant systems:
  - Fractronic 7801, 100 kN, push-pull, up to 1000°C
  - Cracktronic 8024, 70N/m, bending
  - Resonant system Schenck PVQ, 60 kN, push-pull
  - Servohydraulic system Shimadzu 10kN
Low cycle fatigue fractures are connected with the infrequent working cycles of equipment or instruments which often result from start-up and shut down operations or interruptions of their function. Important subjects represent also high temperature low cycle fatigue, thermal and thermomechanical fatigue and multiaxial elastoplastic fatigue.

Basic goal: Understanding of low cycle fatigue damage mechanisms in various advanced materials at various conditions.

Topics:
- cyclic plastic straining the mechanisms, sources of the cyclic stress and relation to the internal structure.
  Analysis of the hysteresis loop using statistical theory in terms of the internal and effective stress, the relation of the macroscopic response to the internal dislocation structure.
- fatigue damage mechanisms - the mechanisms of cyclic slip localisation, fatigue crack nucleation
- interaction of low cycle fatigue with creep at elevated temperatures, structural changes and damage evolution in high temperature symmetric and asymmetric loading; nickel based superalloys
- effect of the coatings on the cyclic plasticity and fatigue life of advanced materials - effect of nitride and carbon layers and of the other coating procedures on the individual stages of fatigue process and on the fatigue life, e.g Inconel superalloy with Al-Si protective diffusion coating.
- effect of depressed and elevated temperatures on the early fatigue damage - study of the surface relief evolution using high resolution techniques (AFM, FESEM, EBSD, FIB) in austenitic, ferritic and austenitic-ferritic duplex stainless steels
- short crack growth kinetics in advanced steels - duplex, Eurofer, effect of mean stress
LOW CYCLE FATIGUE LABORATORY

MTS 810
± 100 kN,
Teststar Ils electronics
furnace: tests up to 1050 °C

• Mechanical and hydraulic grips for high temperatures
LOW CYCLE FATIGUE LABORATORY

MTS 810

± 100 kN, electronics Teststar IIs, furnace – tests up to 350 °C
cryostat – low temp. test up to -194 °C

• Mechanical and hydraulic grips for high and low temperatures

longitudinal extensometer
LOW CYCLE FATIGUE LABORATORY

MTS 880 ± 50 kN, FlexTestPlus electronics

NAVITAR/QUESTAR: high magnification long-distance microscope equipped with Olympus DP 70 high resolution camera for real-time crack monitoring

Extensometers for longitudinal and transversal deformation
ADVANCED HIGH TEMPERATURE MATERIALS & CREEP OF METALLIC MATERIALS GROUP

- at present 11 scientific co-workers, 4 technicians, 3 PhD. students, 2 MSc. students

Basic mechanisms of high temperature creep in metallic materials, relations between creep behaviour and microstructure and to a transfer of obtained results to technical applications. Experiments include conventional and non-conventional creep tests and structure investigations. The development of new testing facilities and procedures has resulted in a unique equipment of creep laboratories of the Institute.

TOPICS:

Basic research:
- constitutive description of creep behavior
- constant structure creep
- mechanisms of creep in metallic materials at very low creep rates
- creep strength of advanced 9-12%Cr steels
- high-temperature properties of nickel-based superalloys
- creep of intermetallics (Fe-Al, Ti-Al)
- creep in modern magnesium alloys and their fiber strengthened composites
- creep behaviour of ultrafine grained metals and alloys processed by equal channel angular pressing (ECAP)
- modeling of microstructural processes and high-temperature properties in advanced materials

Technical problems:
- possibilities of small punch testing (SPT) in investigations of mechanical behavior of metallic materials
- small punch test method assessment of the residual creep life of service exposed components (including welds)
- actual problems
CREEP LABORATORY

a) 24 lever arm creep machines of own construction allowing
   - either tensile creep tests under constant load
   - or tensile creep tests under constant stress
   - or compressive creep tests under constant load
   maximum load - 8000 N, temperatures from 100 to 1050 °C, use of protective atmosphere (Ar)

b) 5 creep machines of own construction
   - compressive creep tests under constant stress
   maximum load - 8000 N, temperatures from 100 to 1050 °C, possibility of protective atmosphere

c) 3 machines for
   - creep tests with the possibility of quick cooling under stress (load)
   - at present adapted for both types of SPT

d) 2 helicoid specimen creep machines

e) 1 torsion creep machine

f) 2 new 50 kN creep machines up to 1200 (1600) °C within CEITEC in 2012

Continual recording of all tests - PC - own software allowing also recording
some non-conventional tests (e.g., response to \( \sigma \)- or \( T \) changes)
Creep Laboratory

Laboratory no. 1

Laboratory no. 2
Creep Laboratory

Laboratory no. 3

Laboratory no. 4
Creep Laboratory

Helicoid creep machines

Torsion creep machine
BRITTLE FRACTURE GROUP

- at present 6 scientific co-workers, 5 technicians, 4 PhD. students, 2 external PhD. students

Arising from the extensive long-term experiences and previous fruitful and internationally acknowledged activity in this field the group investigates the problems associated with strength and fracture behaviour of engineering materials leading to explanation of physical nature of phenomena observed. Major attention is given to quantitative assessment and predictions of microstructure - property relationships in both the structural steels and the advanced materials. For the recent research activity of the group having theoretical, computational and experimental nature.

Topics:
- **Micromechanisms of brittle failures**, relationships to microstructural parameters. Transition behaviour of fracture toughness characteristics, the temperature and strain rate effects.
- **Micromechanical aspects of brittle fracture initiation**. Accurate characterisation of crack tip phenomena and their relations to macroscopic fracture characteristics, the crack tip constraint effects.
- **Local approach** (deterministic, stochastic) in the assessment of brittle failures and fracture toughness prediction. Cleavage (critical) fracture stress, its physical nature and role.
- **Technological and operational degradation** in low alloy (creep resistant) steels, microstructural and micromechanical properties controlling the phenomena.
- Fracture behaviour and nature of toughness of heterogeneous martensite in low alloyed steels.
- **Fracture of advanced materials**.
- **Strain and fracture behaviour of an in situ composites**. Low temperature toughness and fracture of duplex stainless steels, ageing and strain rate effects.
- **Brittleness and toughening mechanisms in ceramics**. Development of advanced methods for fracture toughness determination for brittle materials.
- The failure micromechanisms and fracture characteristics of glass ceramics reinforced by metal particles and/or SiC fibres.
Brittle Fracture Laboratory

Electromechanical machines: (ZWICK Z50, INSTRON 8862, MTS Tytron 250), temperatures from -196 to +1200°C. Tensile tests, compression tests, 3 and 4 point bending.

High speed hydraulic machine ZWICK rel 1871, up to 6 m/s, temperatures -150 to +25°C.
Brittle Fracture Laboratory

Grindosonic - elastic properties determination using resonance method.


**Instrumented hardness tester** ZWICK Z2.5 ZHU0.2, Vickers, Knoop and universal microhardness tests with max. load 200 N
BRITTLE FRACTURE LABORATORY

High speed camera Olympus i-SPEED 3:

Extremely high sensitivity and speed up to 150,000 frames/s.

Confocal microscope Olympus LEXT OLS3100 with AFM modul for documentation of microstructure and fracture surfaces, 3D reconstruction of surfaces and their further geometrical analysis.
DIFFUSION AND THERMODYNAMIC GROUP

- at present 5 scientific co-workers, 3 technicians

The activities of the group are concentrated on the investigation of volume diffusion and diffusion along high-diffusivity paths, on chemical diffusion under concentration gradients in multiphase materials and in weldments, on measurements of thermodynamic properties of alloys in solid state and calculation of thermodynamic characteristics and on investigation of diffusion of gasses in solids. Diffusion processes are studied close to surface of chosen Ni alloys for heat exchange systems of nuclear reactors exposed to molten cooling media (halide salts).

Following topics have been studied in last five years:

- Bulk and grain boundary diffusion in Mg alloys both with and without ceramic reinforcement.
- Bulk and grain boundary diffusion in amorphous FINEMET and NANOPERM - type alloys.
- Bulk and grain boundary diffusion in nickel.
- Diffusion of hydrogen in Mg, Mg-xNi and Mg-xNi-yX alloys with the third element X (X = Zn, Ga, In, Si, Ge a Sn).
- Changes of local chemical composition are studied in chosen Ni alloys exposed to molten halide salts.
- Iron diffusion in Fe-based bulk metallic glasses.
ELECTRICAL AND MAGNETIC PROPERTIES GROUP

- at present 12 scientific co-workers, 4 technicians, 1 PhD. student, 1 MSc. student

The activities of the group are focused on:
- theoretical studies of electronic and magnetic properties of disordered alloys, epitaxial multilayers, surfaces and interfaces as well as quantum-mechanical studies of extended defects in metallic materials
- experimental investigations of relations among structure and magnetic, transport and mechanical properties in metallic materials

The most important topics within last five years have been oriented on:
- first-principles investigations of two-dimensional alloy magnetism and electron transport in magnetic multilayers
- first-principles studies of theoretical strength, phase stability and magnetism in metals and intermetallics
- atomistic studies of grain boundaries in metallic materials and development of relevant quantum-mechanical techniques
- influence of method of preparation, heat and mechanical treatments on structure and properties of nanocrystalline materials
- structure and properties of metallic and oxidic magnetic materials prepared by non-traditional technologies
- role of defects in electrical, magnetic and mechanical properties of ordered intermetallic systems.
STRUCTURE OF PHASES GROUP

- at present 4 scientific co-workers, 6 technicians

The research activity of the group is concentrated on:
- experimental study of internal microstructure of materials in connection with phase transformations and thermodynamic modelling, phase diagrams and phase compositions prediction of multicomponent alloy systems, kinetics of phase transformations, CALPHAD method.

The most important projects solved by the group in the last five years are:
- theoretical and experimental study of Ni-based model systems and thermodynamic description of phase equilibria
- ordering processes in Ni-based superalloys studied by Monte-Carlo simulation
- the development of modern high Cr materials through the theoretical modelling
- intelligent welding of power generation components
- theoretical and experimental assessment of phase diagrams of lead-free solders, mainly Zn-Sn-In-(Bi)-(Pd) systems
- influence of phase composition of Mg alloyed with rare earthes on the improvement of its utility properties at elevated temperature
- microstructural assessment of 9%Cr steels after long term creep at high temperature, thermodynamic modelling of phase diagrams and precipitates behaviour (Laves phase, Z – phase …)
- structural stability of weld joints of creep resisting chromium steels and their degradation during long-term operation
- structure examination in nickel intermetallics
LABORATORY OF ELECTRON MICROSCOPY

- Electron tubus
- Ion tubus
- nanomanipulator
- EDX analyzer (Brucker)
- GIS (Pt, W, water, isolator, floridum)
- BSE detector
- SE detector
• TESCAN LYRA 3 XMU chamber view

- EDX analyzer (Brucker)
- Electron tubus
- Nanomanipulator
- Iontovy tubus
- BSE detector
- SE detector
- GIS
Ion dust off of ditch to create thin lamella for TEM

Ion cut off around lamella
Approach of needle to lamella and its welding with help of platinum overlay
2. Finished Projects

2007 – 2009 Czech Science Foundation project no. 106/07/1507
Low cycle fatigue-creep interaction in advanced high temperature structural materials
investigator: Karel Obrtlík
materials studied: Ni-based superalloys (IN713LC, IN738LC and IN792-5A).

2005 - 2007 Czech Science Foundation project no. 106/05/0918
NiTi Shape Memory Alloys and Their Processing-Structure-Transformation Relationship, investigator: Antonín Dlouhý

2002 - 2005 Ministry of Education, Youth and Sports project no. OC 526.60
A Numerically Based Optimization of a Near-gamma TiAl Precision Casting Process, investigator: Antonín Dlouhý

1999 - 2001 Czech Science Foundation project no.106/99/1649
High-temperature properties of Ni-Cr-W-C systém, investigator: Václav Sklenička
3. Running Projects

since 2008 Euratom projects:
• Study of the micro-mechanism of cleavage fracture of 14%Cr ODS ferritic steels
• Nano-structured ODS Ferritic Steels Development
  cooperation with CEA, Fr (Dr. B. Fournier)
  cooperation with the Paul Scherrer Institute, CH (prof. N. Baluc)
  co-investigator: Tomáš Kruml

2006 - 2011 Commission of the European Communities AST5-CT-2006-030889
Predictive Methods for Combined Cycle Fatigue in Gas Turbine Blades
(PREMECCY) co-investigator: Petr Lukáš

2011-2015 Commission of the European Communities FP7-PEOPLE-2010-ITN, 264526
Glass and Ceramic Composites for High Technology Applications – Initial Training Networks (GLACERCO) co-investigator: Ivo Dlouhý

2009-2012 European Science Foundation CZ.1.07/2.4.00/12.0030
Mechanical Engineering Cooperative Network co-investigator: Ivo Dlouhý
3. Running projects

2011 - 2013 Czech Science Foundation project no. P107/11/2065
Protective diffusion coatings on cast nickel-based superalloys for high temperature application, investigator: Karel Obrtlík

2011 - 2013 Czech Science Foundation project no. P204/11/1453
Analysis of cyclic stress components in advanced nickel-based superalloys Inconel using neutron diffraction and TEM, investigator: Martin Petrenec

2011 – 2014 Czech Science Foundation project no. P107/11/0704
Optimization of structure and fatigue-creep properties of new advanced gamma based TiAl-8Nb-X alloys alloyed with C and Mo by complex heat treatment, investigator: Martin Petrenec

2009 - 2012 Czech Science Foundation project no. GA101/09/1821
Mechanical and fracture properties of multilayered ceramic/ceramic and ceramic/metal materials with graded layers, co-investigator: Ivo Dlouhý
3. FUTURE PROJECTS

IPM has strong interest in initiation and participation on advanced material projects, development of new materials and new testing methods.

Sources:
- Grant Agency of the Czech Republic (GACR)
- Technological Agency of Czech Republic (TACR)
- Ministry of education (MSMT)
- Ministry of industry (MPO)
- EU – 8th FP (from 2014)
- COST
- Industrial cooperation: IPM has long term cooperation with about 15 industrial partners